HRSD SWIFT Research Center (SWIFTRC): Nitrite Primary Maximum Contaminant Limit (PMCL) Exceedance and Corrective Action Report

Nitrite PMCL Exceedance in the SWIFT Water

Description of the Event and Cause:

Beginning June 6 and ending June 21, 2018, 11 of 15 sample days exceeded the 1 mg/L PMCL for nitrite (Table 1); aquifer recharge occurred on ten of these eleven days. The maximum value during this period was 1.35 mg/L and the average was 1.06 mg/L. The average nitrite value for the month of June was 0.82 mg/L. The total volume recharged on these dates was approximately 4.8 million gallons.

Date	Nitrite (mg/L)
6/1/2018	0.71
6/2/2018	0.62
6/3/2018	0.74
6/4/2018	0.82
6/5/2018	0.96
6/6/2018	1.07
6/7/2018	1.16
6/8/2018	NS
6/9/2018	0.98
6/10/2018	1.02
6/11/2018	1.01
6/12/2018	1.01
6/13/2018	1.08
6/14/2018	1.01
6/15/2018	0.97
6/16/2018	0.96
6/17/2018	1.04
6/18/2018	0.89
6/19/2018	1.08
6/20/2018	1.21
6/21/2018	1.35
6/22/2018	0.82
6/23/2018	0.75
6/24/2018	IS
6/25/2018	0.53
6/26/2018	0.48
6/27/2018	0.38
6/28/2018	0.23
6/29/2018	0.10

Date	Nitrite (mg/L)
6/30/2018	0.08
Average June 6 – June 21	1.06
Monthly average	0.82

Table 1: Nitrite in SWIFT Water in June 2018. NS: No sample collected. Advanced Water Treatment (AWT) operations suspended for six hours during sample collection period. IS: Improper sample. The sample did not meet preservation requirements and was not analyzed.

The identification of the PMCL exceedance did not occur until August 2, 2018 as part of preparation for the SWIFTRC quarterly report due to EPA Region III, the Virginia Department of Health (VDH) and the Virginia Department of Environmental Quality (DEQ) in September.

With the consistent load of about 1 mg/L ammonia-N to the biofilters, the establishment of nitrification routinely involves the initial establishment of ammonia oxidizing bacteria (AOB) which produce nitrite. After AOB are established and are producing nitrite, nitrite oxidizing bacteria (NOB) then follow, oxidizing nitrite to nitrate. This is exactly what happened, as shown in Figures 1 and 2.

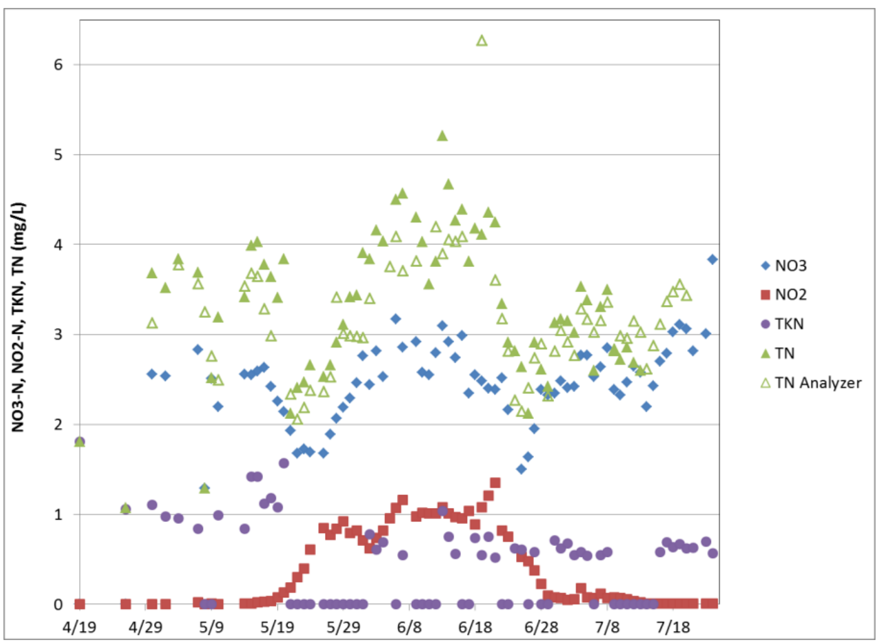


Figure 1. SWIFT Water nitrogen species. Note that the remaining TKN in the SWIFT Water after the establishment of full nitrification represents the ammonia added as part of preformed monochloramine to protect the wellhead from biofouling and a small amount of remaining dissolved organic nitrogen.

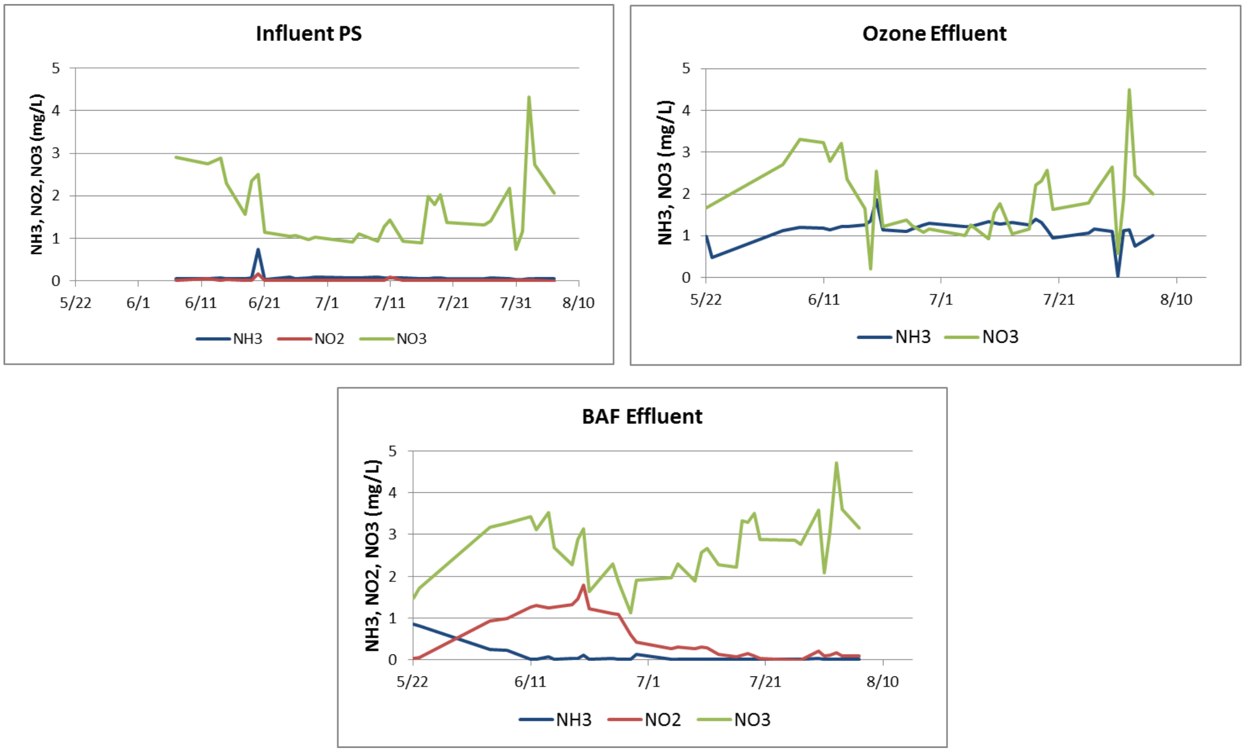


Figure 2. Nitrogen species throughout the SWIFT treatment system. Note the initial accumulation of nitrite in the BAF effluent, followed by complete oxidation of ammonia to nitrate.

As a result, the short-term accumulation of nitrite in the SWIFT Water was not unexpected and was clearly a result of incomplete nitrification in the biofilters. From the beginning of operations of the SWIFTRC advanced water treatment (AWT) process, nitrification in the biofilters has been closely monitored. Despite this careful evaluation staff focus was on nitrification and biological activity within the biofilters as well as strict compliance with the nitrate MCL, the total nitrogen (TN) treatment objective, and the total inorganic nitrogen (TIN) critical control point, and not on compliance with the nitrite MCL.

Performance of the biofilters continues to be closely monitored. July and August monitoring to-date of SWIFT Water confirms the maintenance of nitrification in the biofilters with a maximum daily nitrite concentration of 0.27 mg/L (July 31).

This exceedance was controllable and avoidable from a treatment process perspective. The SWIFT treatment system includes the addition of preformed monochloramine ahead of the recharge well for biofouling protection. A switch from monochloramine to free chlorine addition to the SWIFT Water could have been made and all of the nitrite would have been removed. Free chlorine oxidizes nitrite to nitrate stoichiometrically, completely, and nearly instantaneously. This is a lesson learned for future SWIFT installations.

It is important to note that the tasting system which is operated periodically during tours of the SWIFTRC, was not impacted by this high nitrite. In order to achieve an additional 4-log removal of viruses, the tasting system water is disinfected in a separate 30-minute chlorine contact pipeline with free chlorine which, as previously described, oxidizes nitrite to nitrate nearly instantaneously. The tasting system is carefully monitored during tasting events to confirm a free chlorine residual of at least 0.5 mg/L.

Corrective Action:

Failure to Identify PMCL Exceedance: Though online sensors associated with critical control points are designed to trigger real-time alerts and diversion of SWIFT Water from the recharge well when necessary, the laboratory-generated data was not linked to automated triggers such as a PMCL exceedance. In an immediate response, on August 3 HRSD's laboratory analysts began manually evaluating SWIFT Water data relative to established trigger values so that immediate notification could be made to the appropriate staff. In order to automate the process and reduce the potential for human error, as of August 6, HRSD's laboratory established automated triggers within its Laboratory Information Management System (LIMS) Sample Manager (HRSD's data management software platform) for all parameters that have a regulatory target (e.g., PMCL, groundwater protection standard, etc.) to alert the analyst and appropriate SWIFT team members of an exceedance. An alert will trigger an immediate in-depth data review by the analyst and the laboratory manager to ensure the validity of the data. If the data is valid, SWIFT Water will be diverted to the Nansemond wastewater treatment facility and within 24 hours a confirmation sample for laboratory analysis will be collected. Recharge operations will not resume until confirmation is made that the regulatory parameter is below the limit. SWIFTRC staff will discuss treatment adjustments that may be needed to avoid similar exceedances in the future.

SWIFT Water nitrite in excess of the PMCL: An online nitrite analyzer was installed on August 7, 2018 at the Granular Activated Carbon combined effluent (GAC CE) sample point to monitor in real-time nitrite levels within the SWIFT Water.

The output of this analyzer has been connected to the plant distributed control system (DCS). A critical control point (CCP) has been developed which includes an alert level at 0.25 mg/L and an alarm level at 0.5 mg/L NO_2-N. A nitrite concentration which triggers an alarm will result in automatic diversion of SWIFT Water away from the recharge well. The CCP will be tested before August 20, 2018. Though the biofilters are fully nitrifying at this time, periodic upsets may trigger nitrite values that require the diversion of the water away from the recharge well or the addition of free chlorine to remove the nitrite present before entering the aquifer.

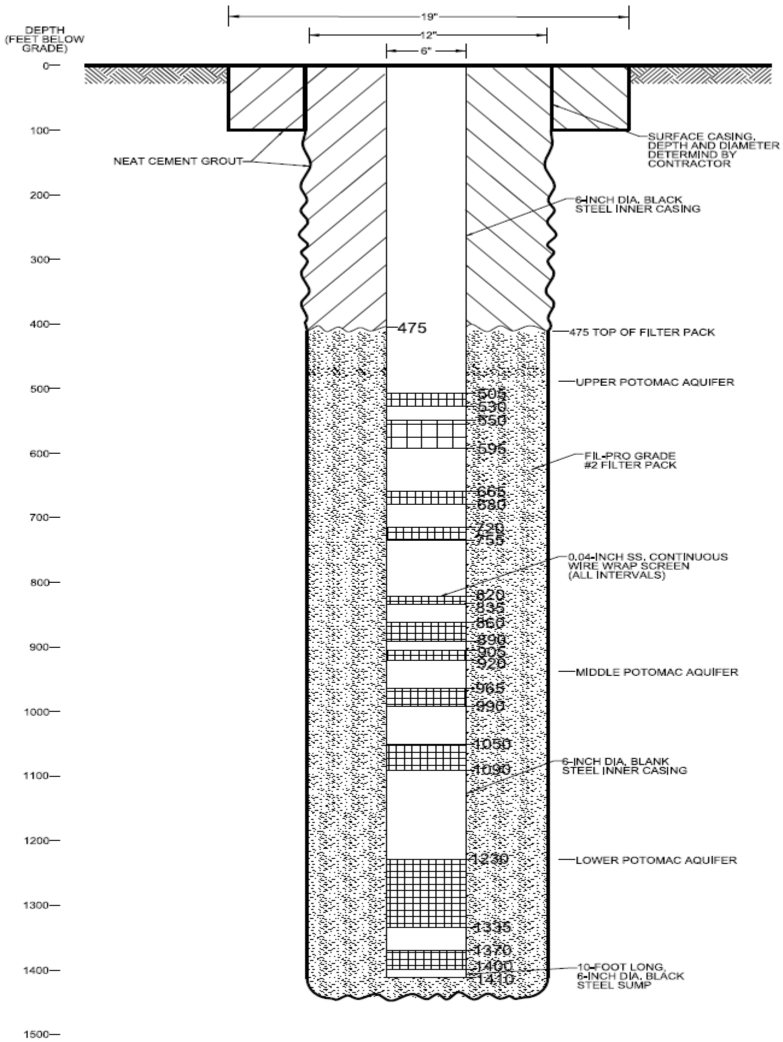
Other than short term upsets in nitrification (e.g., colder temperatures over winter), we do not expect SWIFT Water nitrite to exceed or even approach the PMCL for a sustained period. Nonetheless, we are prepared for that possibility. If the CCP alarm level is violated, SWIFT Water will be diverted through an automated process. Though nitrite elevated above the alarm level for a prolonged period of time is not expected, the SWIFTRC was designed with the flexibility to manually shift SWIFT Water from monochloramine to free chlorine addition to oxidize the nitrite to nitrate. In this event, the nitrite CCP would be disengaged and replaced by an existing CCP that ensures free chlorination by online measurement of GAC CE ammonia using an existing online analyzer. This GAC CE ammonia CCP was included as part of the original SWIFTRC design but has been disengaged since startup. It was intended to ensure free chlorination under the operating condition where free chlorine is required for virus inactivation.

Nitrite PMCL exceedance in MW-SAT:

Description of the Event and Possible Contributing Factors:

On August 2, review of the data from a monitoring well located 50 ft away from the recharge well (MW-SAT, schematic in Figure 3) identified three discrete monitoring screen intervals in which nitrite data had exceeded the PMCL. The other eight discrete screen intervals in MW-SAT have not recorded nitrite values in excess of the PMCL, either because the travel time to the interval has not been achieved, or the chemical and biological conditions in the interval have reduced nitrite prior to MW-SAT. Sampling in each interval was independently triggered based on the presence of a tracer indicating that the recharge water was present in the interval. The trigger for initiating sampling in screen interval 1 was based on a reduction in fluoride concentrations while the trigger for initiating sampling in the screen intervals was based on a reduction in conductivity. The variable rate of travel in each screen interval resulted in different sampling schedules. Note that conductivity was originally planned to serve as the tracer for all intervals. However, baseline interval monitoring in the spring of 2018 indicated that the conductivity in interval 1 was similar to the expected conductivity in SWIFT Water. Fluoride, however, was higher in interval 1 than what would be expected in SWIFT Water. Based on this finding, fluoride was identified as the better tracer for interval 1.

Though nitrate concentrations during the month of June approached ½ of the 10 mg/L PMCL for nitrate (Figure 2), SWIFT Water has been compliant at all times with the TN requirements of 5 mg/L monthly average and 8 mg/L maximum day, and most of the nitrogen in the SWIFT Water is present in the form of nitrate (Figure 2). Furthermore, MW-SAT data suggest very good removal of nitrate in the aquifer through denitrification (Figures 4 and 5).



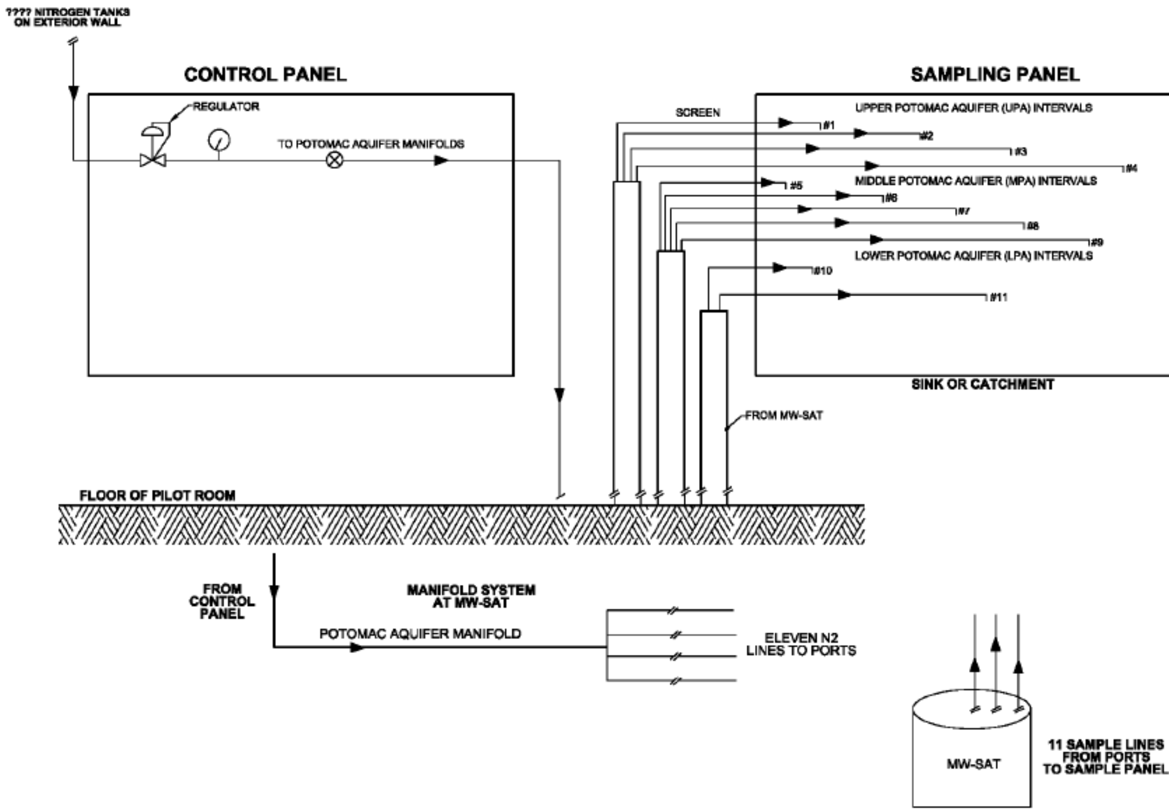


Figure 3: Paired schematics of the MW-SAT Monitoring Well identifying the depths of each of the 11 discrete sampling intervals, their location within the Potomac Aquifer, and the associated sampling ports.

Screen Interval 1: Daily nitrite sample collection in Interval 1 began on June 11 and ended July 24. With the exception of June 11, June 23, and July 18-24, samples were collected twice daily. The average daily nitrite concentrations during this period relative to the PMCL are plotted in Figure 4 along with results for the other two intervals that exhibited nitrite concentrations exceeding the PMCL. The first average daily nitrite result in excess of the PMCL occurred on June 11 with the majority of the results through July 24 in excess of the PMCL. The highest observed value during this period was 1.73 mg/L. The average nitrite concentration of the recorded samples during this period was 1.12 mg/L. A more recent analysis on August 3 identified a present-day nitrite concentration of 1.15 mg/L (Table 2).

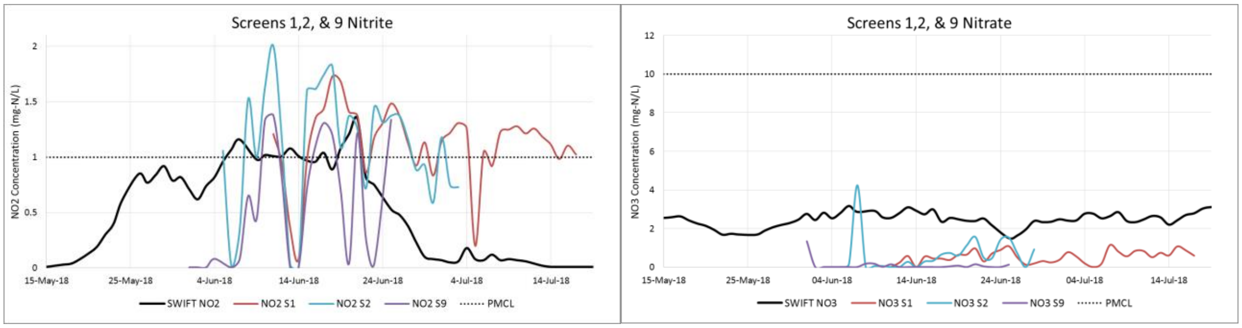


Figure 4: Average Daily Nitrite and Nitrate Concentrations in MW-SAT Screen Intervals 1 (S1), 2 (S2) and 9 (S9) relative to the nitrite PMCL and SWIFT Water concentrations (SWIFT).

Sample Point	Nitrite (mg/L)
MW-SAT S1	1.15
MW-SAT S2	0.42
MW-SAT S3	0.75
MW-SAT S4	<0.01
MW-SAT S5	<0.01
MW-SAT S6	0.01
MW-SAT S7	<0.01
MW-SAT S8	<0.01
MW-SAT S9	<0.01
MW-SAT S10	0.04
MW-SAT S11	<0.01
MW_UPA	<0.01
MW_MPA	<0.01
MW_LPA	0.02

Table 2. Nitrite monitoring data from August 3, 2018 for MW-SAT Screen Intervals 1-11 (S1-S11) and the conventional monitoring wells for the Upper Potomac (MW_UPA), the Middle Potomac (MW_MPA), and the Lower Potomac (MW_LPA).

Screen Interval 2:

Daily nitrite sample collection in Screen Interval 2 began on June 5 and ended July 3. Twice daily samples were collected from June 6 – June 28 with the exception of June 23. Once daily sampling continued through July 3. The average daily nitrite concentrations for this period relative to the PMCL are plotted in Figure 4. The first average daily nitrite result in excess of the PMCL occurred on June 8 and subsequent sample concentrations fluctuated around the PMCL through June 27. From June 27 – July 3, all results were less than the PMCL with the exception of July 1. The highest observed value was June 11 with 2.01 mg/L. The average nitrite concentration of the recorded samples during this period was 1.11 mg/L. A more recent analysis on August 3 identified a present-day nitrite concentration of 0.42 mg/L (Table 2).

Screen Interval 9:

Twice daily monitoring of Interval 9 occurred June 1 – June 19, followed by once daily monitoring through June 26. The average daily nitrite concentrations for this period relative to the PMCL are plotted in Figure 4. The first date in which the average daily nitrite concentration exceeded the PMCL was June 10. The data collected during this time frame exhibited variability, ranging from non-detect to 1.38 mg/L. The average nitrite concentration of the recorded samples during this period was 0.55 mg/L. A more recent analysis on August 3 identified a present day nitrite concentration of <0.01 mg/L (Table 2).

Though documented exceedances of the nitrite PMCL occurred in SWIFT Water in the month of June, it does not appear to be the sole source of nitrite present within the aquifer. Each of the three screen intervals in which nitrite concentrations exceeded the PMCL exhibited periodic concentrations of nitrite in excess of that present in SWIFT Water. Though recharge water was present in eight intervals, only three demonstrated high nitrite concentrations. Current monitoring indicates that nitrite concentrations in Interval 3 are increasing, despite the fact that nitrite concentrations in the SWIFT Water have been < 1 mg/L since June 21. Figure 5 shows average daily Nitrite concentrations in screens 3-7. Note that sampling had not yet begun in screens 8, 10, and 11, so there is no nitrate or nitrite data available for this time period. Additional samples were collected August 3 and the results are presented in Table 2.

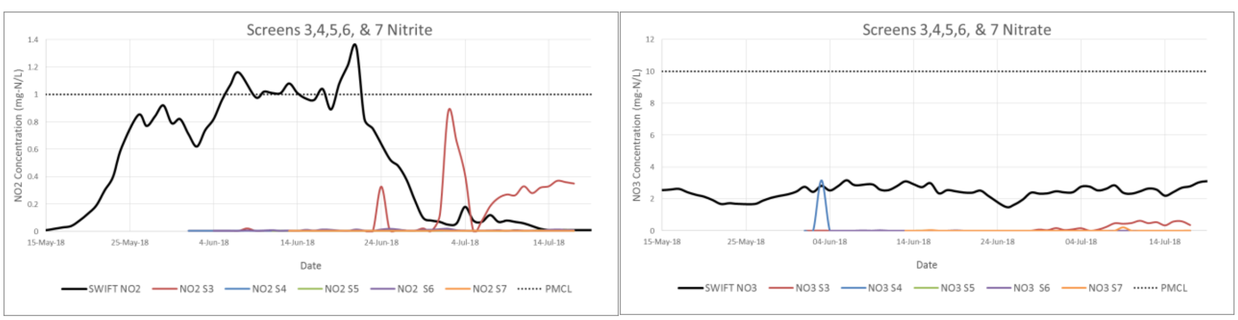


Figure 5: Average Daily Nitrite and Nitrate Concentrations in MW-SAT Intervals 3-7 (S1-S7) relative to the nitrite PMCL and SWIFT Water (SWIFT).

Though elevated SWIFT Water concentrations may have contributed to the PMCL exceedances seen in three of the intervals, it appears as though additional nitrite formation is occurring as a result of reducing conditions within these intervals. For this level of presumed nitrite production in the aquifer, one should expect significant nitrate removal in the aquifer. As expected, the removal of nitrate in the aquifer, comparing SWIFT Water to MW-SAT data is quite encouraging, and is significantly more than the presumed production of nitrite in the aquifer (Figures 4 and 5). The three month average concentration for nitrate in recharge water (May – July) was 2.6 mg/L. It is likely that a portion of the nitrate present in the SWIFT Water is being converted to nitrite under these reducing conditions. It is anticipated that the presence of nitrite is a temporary condition as the nitrite is expected to continue to reduce to nitrogen gas, as part of the denitrification process, once the biology in the aquifer acclimates to the recharge water. Though organic carbon in the recharge water is limiting (May-July Total Organic Carbon (TOC) average concentration: 0.58 mg/L), groundwater data for ferrous iron and sulfide from these intervals suggests the availability of electron donors to facilitate the reduction of nitrate (Figure 6).

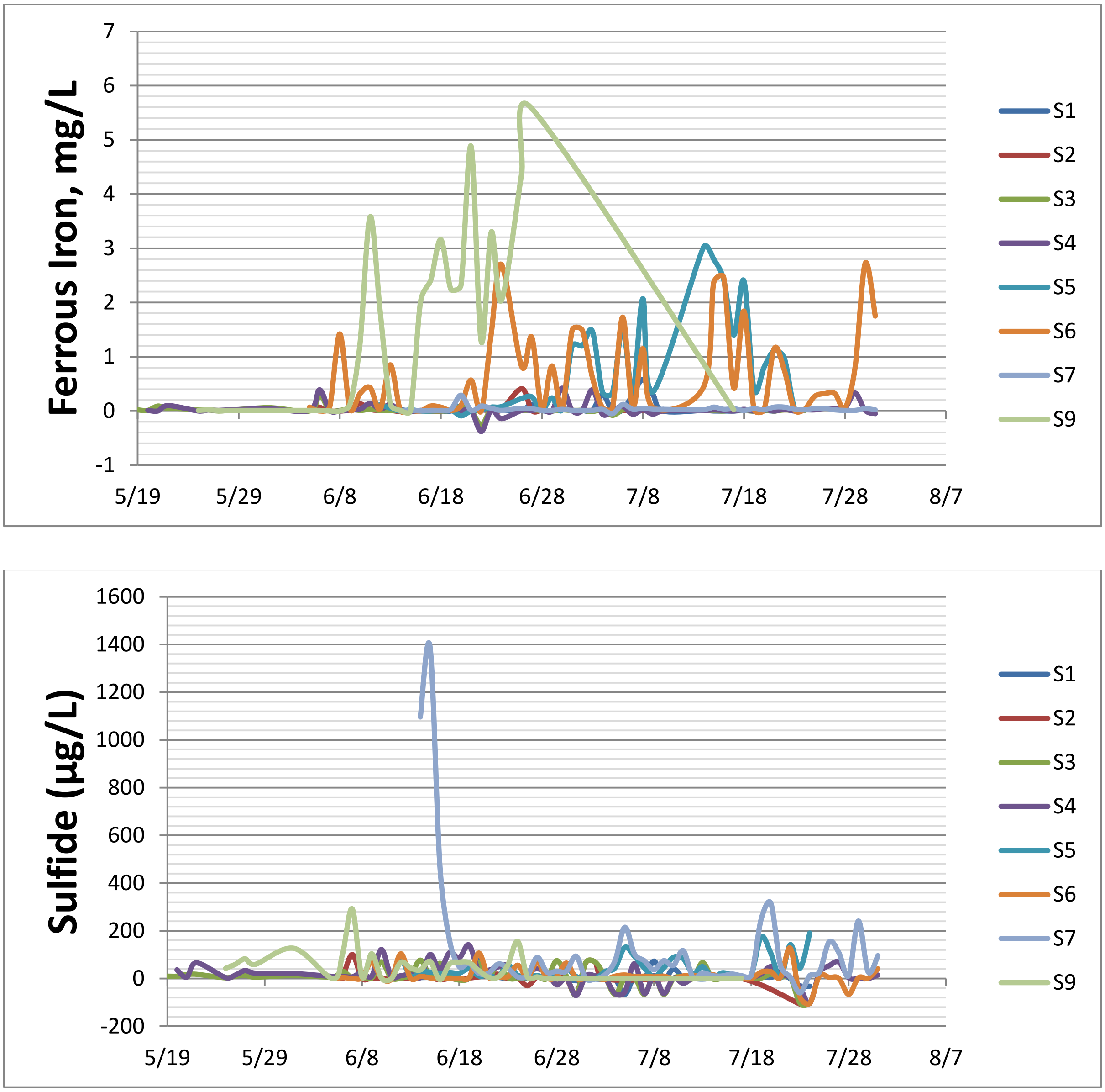


Figure 6. Ferrous iron and sulfide concentrations from MW-SAT Screen Intervals receiving recharge (S1-S7, S9).

Using continuous flow soil columns fed with SWIFT Water produced by the small pilot system and designed to simulate soil aquifer treatment in the Potomac Aquifer, HRSD evaluated contaminant removal across a wide range of parameters. This testing demonstrated a similar temporary increase in nitrite in a soil column simulating ~3 days travel time (representative of MW-SAT), followed by good nitrate and nitrite removal after one month of travel time (Figure 7). Based on this information, it is expected that soil aquifer treatment will reduce nitrite levels with time and travel distance. On August 3 nitrite monitoring of the outer lying conventional monitoring wells located approximately 400 - 500 ft south of the recharge well on August 3 indicated that nitrite concentrations in the upper and middle Potomac were below detection (<0.01 mg/L) while the nitrite in the lower Potomac was 0.02 mg/L (Table 2).

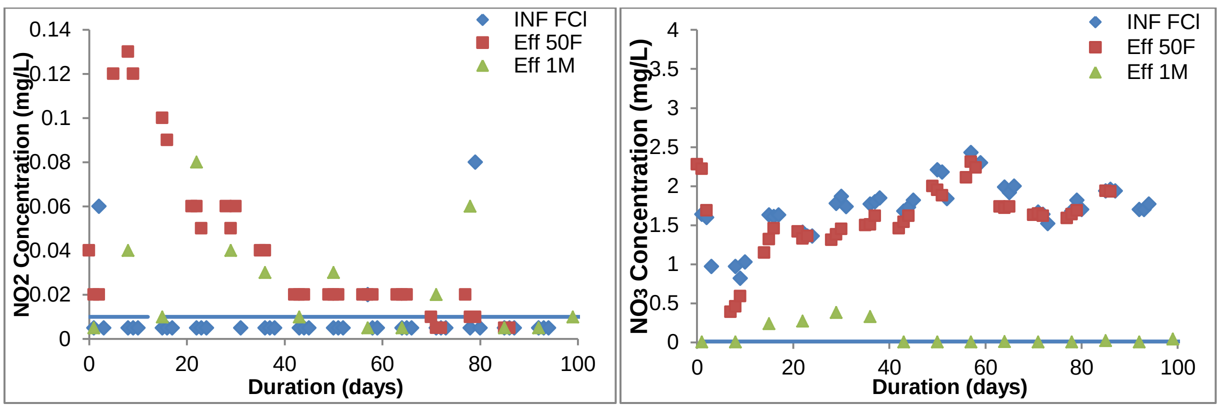


Figure 7: Nitrite and nitrate removal through soil aquifer treatment as measured in continuous flow soil columns packed with cleaned sand collected during monitoring well drilling operations. The column effluent samples are temporally corrected based on actual tracer-study measured travel times such that a direct comparison can be made between influent and effluent quality. The soil columns were operated with a continuous SWIFT Water feed from the pilot treatment train for a period of approximately 3 - 4 months. INF FCl: Source water for the soil columns that was disinfected by free chlorination. Eff 50F: Effluent from the simulated 50ft well which represents approximately 3 days of travel time. Eff 1M: Effluent from the 1 month column which represents approximately 30 days of travel time.

Nitrite is very unstable in the groundwater environment and would not be expected to persist, converting readily to nitrate in aerobic conditions and to nitrogen gas in anaerobic/anoxic conditions. Though it may not be possible to prevent the formation of nitrite in excess of the PMCL in the aquifer in the immediate vicinity of the recharge well while reducing conditions remain, it is anticipated based on the instability of this compound and its removal in the soil columns, that nitrite in excess of the PMCL would not migrate far from the recharge well. Though nitrite is not expected to be conserved, better information on travel time would be helpful in understanding the potential areal extent of nitrite movement. A refined estimate on travel time for the recharge water is not yet available as data collection efforts are on-going. However, the conventional monitoring wells will continue to be monitored daily for the presence of nitrite (and nitrate) to evaluate the areal extent of migration.

Corrective Action:

In an abundance of caution, HRSD has elected to remove the recharge water from the recharge well (Test Well-1, "TW-1") by backflushing the well at ~1100 gpm or ~160% of the recharge flow rate, returning the flow to the head of the chlorine contact tanks within the Nansemond wastewater treatment plant and ultimately discharging through its outfall located in the James River in compliance with the facility's Virginia Pollutant Discharge Elimination System permit. Backflush of the well was initiated at approximately 9:30 pm on August 3.

Nitrite values will be monitored daily in the backflush water and in each of the eleven discrete sampling screen intervals in MW-SAT. In addition, nitrite monitoring of the outer lying conventional monitoring wells will occur daily. After each of the eleven discrete intervals and backflush water have documented nitrite concentrations < 0.5 mg/L (½ of the PMCL), the well will continue to be backflushed for an additional seven days to provide an added safety factor and to ensure that elevated concentrations of nitrite no longer remain in the recharge well or its vicinity.

Once recharge operations resume, more frequent monitoring of nitrite will continue with daily observations of both nitrate and nitrite collected from each of the MW-SAT screen intervals in which recharge water is present along with on-going daily monitoring in the conventional monitoring wells.

Monitoring frequency in MW-SAT will be reduced to match the routine PMCL monitoring frequency once it is clear that the reducing conditions which facilitate nitrite formation are no longer present, though it is possible that nitrite will continue to be detected at MW-SAT in the future indicating partial denitrification is occurring in the aquifer in the short distance (50-feet) between TW-1 and MW-SAT. Monitoring frequency in the conventional monitoring wells will be reduced to match the routine PMCL monitoring frequency once it ascertained that the recharge front has migrated past each well, provided that there is no evidence of nitrite migration or formation at each of the wells.

It is important to note again that it is possible that the nitrite concentrations in one or more of the sampling intervals in MW-SAT may exceed the PMCL not as a result of nitrite in SWIFT Water but rather due to nitrate conversion in the aquifer. If this problem recurs, HRSD will not necessarily repeat the well backflush to remove nitrite from the recharge well. Instead, HRSD will maintain daily observation of the nitrite in the conventional monitoring wells to confirm that nitrite has not migrated off-site and that the potable water supply for surrounding communities is not impacted. Furthermore, HRSD will investigate the overall benefit provided by denitrification in the aquifer and complete removal of nitrate through soil aquifer treatment and insitu denitrification.

Overall Evaluation:

The SWIFT Research Center was envisioned as a learning step in the SWIFT process. It was built to understand how to operate a large, complex advanced water treatment process as well as to understand what happens with SWIFT Water as it moves through the aquifer, interacting with native groundwater and sediments. As part of this process and in recognition of the research and learning opportunities associated with managed aquifer recharge, we voluntarily developed a sampling and analysis plan with a high frequency of monitoring for PMCLs and we are holding ourselves to strict compliance with the PMCL for each individual sample collected. At this time, there is still much to understand regarding travel time and the availability of soil aquifer treatment and so strict compliance for recharged SWIFT Water seems entirely appropriate. Our continued operations and data collection will provide many of these answers and inform full-scale implementation efforts.

Thinking in advance about full-scale implementation, given the expected travel time within the aquifer and the lack of private well users in the immediate vicinity of the SWIFT facilities, establishing a variable monitoring frequency and averaging period for evaluating PMCL compliance would likely be appropriate on a parameter-by-parameter basis. This practice is consistent with the Virginia Waterworks regulation which allows variable monitoring frequencies and averaging periods for drinking water utilities in considering compliance with specific MCLs. If this approach is appropriate for drinking water utilities which have a more direct connection to consumers and public health protection, then some variation of this should be appropriate for SWIFT permitting. The challenge is acknowledging that the nature of the source water for SWIFT may require a different approach while also recognizing the lack of proximal users and the function of the aquifer as an environmental buffer in public health protection. This warrants consideration in identifying an appropriate monitoring frequency and averaging period for evaluating compliance. This appears to be the type of question and discussion that would be appropriately held with the SWIFT Oversight Committee once more data becomes available and the Committee is officially engaged.

We have learned a great deal with this situation and these lessons will be applied to make the next steps with SWIFT more reliable. Pulling recharge water back out of the aquifer allows us to formally demonstrate HRSD's commitment to the reliability of SWIFT. Our quarterly report to EPA, VDH and DEQ will document the results of this process.